Available online at www.sciencedirect.com
SciVerse ScienceDirect
Energy Procedia 32 (2013) 11 – 20
Energy Procedia

International Conference on Sustainable Energy Engineering and Application

[ICSEEA 2012]

Analysis and choice of energy generation technologies: the multiple criteria assessment on the case study of Lithuania

Jurate Sliogeriene[a, b,*], Zenonas Turskis[b], Dalia Streimikiene[a]

[a] *Lithuanian Energy Institute, Breslaujos 3,LT- 44403, Kaunas, Lithuania*
[b] *Vilnius Gediminas Technical University, Sauletekio al. 11, LT-2040 Vilnius, Lithuania*

Abstract

Increasing fossil fuel prices and growing dependence on energy imports will encourage many countries to review their development strategy and plans for energy. Choice of the appropriate solution to be applied within energy sector is a complicated problem: great number of alternatives and criteria shall be analyzed and evaluated paying additional attention to the controversial social, economic, technological and environmental factors. Since the Pareto optimal solution does not exist, the most appropriate solution can be made upon the evaluation of generality of conditions and provisions in the way of negotiations. The paper presents the process of choice of Lithuania's energy generation technologies, which has been solved using multiple criteria mathematical methods such as AHP (Analytic Hierarchy Process) and ARAS (Additive Ratio Assessment method). The derived results show that in case of Lithuania it is viable to consider further development of the nuclear power generation capacity. Among the energy generation technologies related to renewable energy sources a clear priority is assigned to biomass technologies. The research results discussed in the article suggest that assessment and choice of energy generation technologies using multiple criteria methods is a good way to agregate the criteria of performance, economic expedience and ecological integrity with the criteria of technological innovativeness, socially-responsible operation and sustainable development.

Selection and peer-review under responsibility of the Research Centre for Electrical Power and Mechatronics, Indonesian Institute of Sciences.

Keywords: Energy generation technologies; decision support; multiple criteria analysis; renewable sources; nuclear sources.

* Coresponding author: Tel: +370-606-34834;
E-mail: sliogeriene.j@gmail.com

Selection and peer-review under responsibility of the Research Centre for Electrical Power and Mechatronics, Indonesian Institute of Sciences.
doi:10.1016/j.egypro.2013.05.003

1. Introduction

In the course of the year most countries have evaluated the importance of environmental issues, negative impact of fuel on the environment and reconsidered their priorities within energy sector, in order to minimize the dependence on imported energy sources and raw products [1-2]. Accidents that occurred at the Chernobyl and Fukushima-Daiichi nuclear power plants and their severe consequences have renewed attention to the renewable energy technologies. These events brought broad popularity to the reprehension of nuclear energy deficiencies and its potential hazards, and emphasise positive aspects of alternative energy technologies. Still the unbiased assessment proving the above opinion remains undisclosed. At most, the greatest influence is made by public opinion and attitude that are based upon objective evidences on occasion. Particular countries such as Germany, Japan, Italy, and Switzerland that are influenced by clearly stated public opinion have assessed the potential of innovative technology development and abandoned nuclear technologies in order to bet their future on renewable, environment-friendly energy production technologies [3]. Unfortunately, not all countries can put this concept into practice or tolerate it economically. Solutions intended to determine technology implementation or development direction within energy sector shall be made on the basis of compromise between economic, environmental and social arguments and over the divergent, ultimate and frequently politically loaded priorities of deferent groups of interests. In order to perform reasoned assessment of various alternatives and offer appropriate solutions, the multiplicity of data regarding alternative economic variables, their optimum energetic profitableness, environmental impact, social eligibility, technological innovativeness shall be analyzed. Furthermore, criteria (criteria groups) which have a potentially decisive effect on solution making phase shall be properly chosen and analyzed [4].

Several sets of criteria intended for the assessment of sustainability and development level of the energy sector of separate countries in accordance with the state priorities and actual development aspects are prepared and applied [5],[6],[7],[8],[9]. Many of proposed sets of criteria are analogous and introduce the assessment of varying economic, political, environmental, social, and technological dimensions of energy sector. In order to perform analysis and assessment of alternatives, particular multicriteria methods that are broadly used as additional means for development of double standard solutions shall be applied. A variety of multicriteria methods exists in the literature. The decision maker usually decides which method to be used by taking the nature of the problem into consideration. In method selection, the suitability, validity and user-friendliness of the methods are the important factors to be considered [10-11]. Table 1 includes common mathematical methods selected on the basis of scientific literature analysis that are applied for problem solving within energy sector. These methods ensure deeper comprehension of the multidimensionality of problems and promote the involvement of participants into the decision.

2. Methodology

Two multiple criteria methods, namely AHP (Analytic Hierarchy Process and ARAS (Additive Ratio Assessment), have been selected for solution of the task aimed at analysis of the energy generation technologies applied in Lithuania and provision of conclusions regarding the most suitable technologies in view of the Lithuanian situation. These methods have been selected in respect to the possibility to assess external factors influencing selection of technologies from the quantitative and qualitative point of view.

The research is based on the expert assessment of alternatives. The research is organised as the two-level structure: the external factors encompassing institutional – political, technological, economic, environmental protection and social criteria are evaluated in the first level.

Table 1. List of some multi-criteria decision making methods and references

Methods	References
AHP, Fuzzy AHP,	[1], [11], [12], [13], [14], [15], [16], [17], [23]
ARAS	[18]
COPRAS	[8], [16]
Delphi	[17]
ELECTRE, ELECTRE III	[4], [19], [20], [21], [22], [22], [23]
MAUT	[12], [23]
PROMETHEE	[12], [23], [29]
VIKOR	[15], [24]
TOPSIS, Fuzzy TOPSIS	[25], [27], [28], [29], [30]

The analysed alternatives are assessed during the second level. The AHP pairwise comparison method was applied for determination of values of the external factors, as well as values and weights of importance of the criteria characterising these external factors. The analysis of evaluated technologies by determining their value, efficiency, order of priority was performed by applying the multiple criteria method ARAS [18].

The classical approach in decision analysis and multiple criteria decision making theory concentrates on subjective ranking. Most of the multiple criteria decision making methods looks relative distance from the ideally positive or negative solution or compares utility function's scores of available solutions with the ideally positive alternative or with the best or worst alternative of investigated alternatives. ARAS method proposes to compare ratios of utility function's scores of investigated alternatives with an optimal alternatives utility function's score. For example, if an optimal score of criterion is 10 points, but among alternatives under investigation the biggest score of the criterion is 8, ant others are les. In this case it is evident that optimality level of criterion, which is has score 8, is 0.8 but not 1.0 as is in others MCDM methods. Between possible multiple criteria approaches, the ARAS method seems to be most suited for rational objective ranking.

2.1. AHP (Analytic Hierarchy Process) method

AHP is developed by Saaty (1980) [30]. The pairwise comparison is applied for derivation of needed data. The pairwise comparison is used for deriving weights of importance of the criteria and relative rankings of alternatives for each criterion. Ratio scale and the use of verbal comparisons are used for weighting of quantifiable and non-quantifiable elements. The method computes and aggregates their eigenvectors until the composite final vector of weight coefficients for alternatives is obtained. AHP method is widely analysed, including a considerable number and variety of articles written by different authors on application of this method, its advantages and disadvantages [1],[12],[13],[23].

2.2. The determination of priority and importance of considered alternatives by ARAS method

According to the ARAS method, a utility function value determining the complex relative efficiency of a feasible alternative is directly proportional to the relative effect of values and weights of the main criteria considered in a project [18].

The first stage is decision-making matrix (DMM) forming. In the MCDM of the discrete optimization problem any problem to be solved is represented by the following DMM of preferences for *m* feasible alternatives (rows) rated on *n* sign full criteria (columns):

$$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}; i = \overline{0,m}; j = \overline{1,n}, \quad (1)$$

where m – number of alternatives, n – number of criteria describing each alternative, x_{ij} – value representing the performance value of the i alternative in terms of the j criterion, x_{0j} – optimal value of j criterion. If optimal value of j criterion is unknown, then:

$$x_{0j} = \max_i x_{ij}, if \ \max_i x_{ij} \ is \ preferable, and \ x_{0j} = \min_i x_{ij}^*, if \ \min_i x_{ij}^* \ is \ preferable. \quad (2)$$

The system of criteria as well as the values and initial weights of criteria are determined by experts. Then the determination of the priorities of alternatives is carried out in several stages. Usually, the criteria have different dimensions. In order to avoid the difficulties caused by different dimensions of the criteria, the ratio to the optimal value is used. The values are mapped either on the interval [0; 1] by applying the normalization of a DMM. In the second stage the initial values of all the criteria are normalized – defining values x_{ij} of normalised decision-making matrix X:

$$\overline{X} = \begin{bmatrix} \overline{x}_{01} & \cdots & \overline{x}_{0j} & \cdots & \overline{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \overline{x}_{i1} & \cdots & \overline{x}_{ij} & \cdots & \overline{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \overline{x}_{m1} & \cdots & \overline{x}_{mj} & \cdots & \overline{x}_{mn} \end{bmatrix}; i = \overline{0,m}; j = \overline{1,n}. \quad (3)$$

The criteria, whose preferable values are maxima, are normalized as follows:

$$\overline{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \quad (4)$$

The criteria, whose preferable values are minima, are normalized by applying two-stage procedure:

$$x_{ij} = \frac{1}{x_{ij}^*}; \ \overline{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \quad (5)$$

when the dimensionless values of the criteria are known, all the criteria, originally having different dimensions, can be compared.

The third stage is defining normalized-weighted matrix – $\hat{X}$. It is possible to evaluate the criteria with weights w_j. The values of weight w_j are determined by the entropy method. Normalized-weighted values of all the criteria are calculated as follows:

$$\hat{x}_{ij} = \overline{x}_{ij} w_j; \ \ i = \overline{0,m}, \quad (6)$$

$$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \cdots & \hat{x}_{0j} & \cdots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix}; i = \overline{0, m}; j = \overline{1, n}. \quad (7)$$

The following task is determining values of optimality function:

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij}\ ;\ \ i = \overline{0, m}\ , \quad (8)$$

where S_i – the value of optimality function of i alternative. The biggest value is the best, and the least one is the worst. Taking into account the calculation process, the optimality function S_i has a direct and proportional relationship with the values x_{ij} and weights w_j of the investigated criteria and their relative influence on the final result. Therefore, the greater the value of the optimality function S_i, the more effective the alternative. The priorities of alternatives can be determined according to the value S_i. Consequently, it is convenient to evaluate and rank decision alternatives when this method is used.

The degree of the alternative utility is determined by a comparison of the variant, which is analysed, with the ideally best one S_0. The equation used for the calculation of the utility degree K_i of an alternative A_i is given below:

$$K_i = \frac{S_i}{S_0}\ ;\ \ i = \overline{0, m}\ , \quad (9)$$

where S_i and S_0 are the optimality criterion values, obtained from Eq (8). The calculated values of K_i are in the interval [0, 1] and can be ordered in an increasing sequence, which is the wanted order of precedence. The complex relative efficiency of the feasible alternative can be determined according to the utility function values.

3. Case study

The energy generation technologies used in Lithuania and representing the main technology trends of this sector were selected for the research: technologies related to use of fossil fuel and renewable energy sources. The research focuses on the analysis of: 1) designed to be built 1350 MW Nuclear Power Plant, 2) Gas Combined Heat and Power Plant, 3) Biomass Power Plant, 4) Geothermal Power Plant, 5) Hydro Power Plant and 6) the Park of Wind Power Plants.

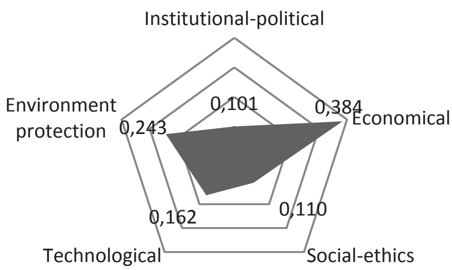

Fig. 1. Weights of the criteria groups

3.1. Expert inquiry

A group of 25 experts was organised for the purpose of the research. The Expert Group consisted of 15 highest ranked managers of enterprises operating in the Lithuanian energy sector, 2 managers of associated structures of energy generation, 3 leading lawyers of the energy generation enterprises, 3 financial specialists and 2 scientists. All members of the Expert Group are graduates of higher education and have experience in the energy sector. The research was performed during the period of November – December of 2011. The weights of importance of the criteria groups (institutional - political, technological, economic, social and environment protection) were determined during the first stage. Based on the evaluation results the economical and environment protection criteria of the energy sector are assigned with the maximum weight of importance. The results are provided in Figure 1.

The decision making matrix is compiled during the second stage related to the evaluation of alternatives. It consists of six energy generation technologies selected for the analysis (two traditional technologies using fossil fuel and four technologies using renewable energy sources for energy generation) and 20 criteria characterizing these alternatives. Criteria values and weights of importance were determined on the basis of the results of the expert inquiry and AHP methodology.

4. Results and discussions

According to the above proposed algorithm of ARAS method the problem was solved and results are presented in Table 2 and Table 3. Table 2 contains initial data of the alternatives - criteria values and weights of importance. Based on data provided in Table 2 it could be concluded that the following 6 criteria having the maximum weight of importance demonstrate the greatest influence on the value of alternatives: “Economic Efficiency”, “Production Cost (Energy Price)”, “Technology’s Competitiveness”, “Value of the Technological Complex”, “Effect on Climate Change and Pollution Cuts”, or “Contribution of RER (Renewable Energy Resources) to the Total Energy Balance”. Based on the expert evaluation the least weight of importance demonstrates the criteria “Support of Government Institutions, Political Organizations”. Table 3 contains the weighted-normalised decision-making matrix and derived alternative evaluation results. Analysis of qualitative and quantitative criteria helped rate the energy generation technologies considering their *institutional* (compliance with international obligations - x_1, legal regulation of activities – x_2, technology’s autonomy (dependence on resource provision) – x_3, support of government institutions, political organizations – x_4, influence on sustainable development of energy – x_5), *economic* (economic efficiency - x_6, technology’s competitiveness – x_7, production cost (energy price) – x_8, value of the technological complex – x_9), *social- ethics* (influence on social welfare (jobs, economic security) – x_{10}, influence on sustainable development of society (education, science, culture) – x_{11}, public acceptance/opinion – x_{12}), *technological* (technology’s rated capacity – x_{13}, technology’s reliability (risk of accidents) – x_{14}, technology’s innovativeness – x_{15}, durability of technology – x_{16}) and *environmental protection* (contribution of RER (renewable energy resources) to the total energy balance – x_{17}, effect on climate change and pollution cuts - x_{18}, treatment of waste - x_{19}, compliance with local natural conditions – x_{20}) aspects and rank them in order of priority.

Analysis of qualitative and quantitative criteria helped rate the energy generation technologies considering their institutional, economic, technological, environmental and social aspects and rank them in order of priority. The estimation results prove that the best alternative is a Nuclear Power Plant. Such results were conditioned by the weight of importance of the economic criteria rated by the experts and positive economical and environment protection characteristics of these technologies. However the research under consideration cannot evaluate the economic capacity of the country to select and implement such extremely costly projects as construction of a nuclear power plant.

Table 2. Initial decision making matrix X

Criterion	Unit	Optimum	W	Nuclear PP	Gas CHPP	Bio PP	Geothermal PP	Hydro PP	Wind PP
				A_1	A_2	A_3	A_4	A_5	A_6
Institutional political criteria									
x1	point	max	0.021	0.338	0.1529	0.918	0.9184	1	0.9184
x2	point	min	0.023	0.961	0.4	0.480	0.4804	0.4803	0.2309
x3	point	max	0.022	0.617	0.1464	1	0.4208	0.8183	0.3566
x4	point	max	0.016	1	0.0936	0.425	0.3476	0.3785	0.3372
x5	point	max	0.019	0.298	0.1455	0.832	0.5109	0.9639	1
Economic Criteria									
x6	%	max	0.125	75	58	44	35	45	23
x7	point	max	0.084	0.7	0.2615	0.453	0.2178	0.4107	0.151
x8	Eur.cnt/kW	min	0.101	0.1	0.092	0.084	0.07	0.06	0.08
x9	Eur/MW	min	0.074	3.800	2850	3.300	1.400	3.200	1.400
Social-ethics criteria									
x10	point	max	0.044	1	0.8	0.637	0.2	0.2	0.1155
x11	point	max	0.033	0.8	0.1046	0.181	0.1813	0.3197	0.2799
x12	point	max	0.034	0.237	0.1643	0.918	0.7025	0.5303	1
Technological criteria									
x13	MW	max	0.031	1300	455	120	35	100	35
x14	point	max	0.054	1	0.453	0.240	0.106	0.2402	0.1155
x15	point	max	0.036	1	0.189	0.124	0.3276	0.0909	0.3276
x16	year	max	0.043	60	30	30	25	30	25
Environmental protection criteria									
x17	%	max	0.068	0	0	100	70	100	100
x18	point	min	0.076	4	3	3	2	1	1
x19	point	min	0.055	0.088	0.215	0.423	0.959	1	0.959
x20	point	max	0.045	0.063	0.08	0.693	0.1714	0.2059	0.2059

The Biomass Power Plant is ranked as the second priority. This priority is ranked as the highest among the four evaluated energy generation technologies related to renewable energy sources. Such result seems to be logical, as a Biomass Power Plant using renewable energy sources plays an important role in ensuring the country's autonomy in the energy generation potential, as well as these technologies are efficient and attractive from the environment protection point of view. The Gas Combined Heat and Power Plant is ranked as the fourth priority. In spite of high level of efficiency, these power plants increase dependency on the import of fossil fuel and receive negative evaluation from the society. The least ranked result is assigned to the Geothermal Power Plant. Despite the fact that Lithuania possesses sufficient geothermal resources, however their use is economically unattractive.

The derived results show that in case of Lithuania it is viable to consider further development of the nuclear power generation capacity. Among the energy generation technologies related to renewable energy sources a clear priority is assigned to biomass technologies.

Table 3. Weighted-normalized criteria values of foundation installment alternatives (weighted-normalized DMM *X*) and solution results

Criterion	Nuclear PP	Gas CHPP	Bio PP	Geothermal PP	Hydro PP	Wind PP	Optimal
	A_1	A_2	A_3	A_4	A_5	A_6	A_{0p}
x1	0.0017	0.0008	0.0045	0.0045	0.0049	0.0045	0.0049
x2	0.0178	0.0010	0.0009	0.0009	0.0009	0.0018	0.0178
x3	0.0040	0.0009	0.0065	0.0027	0.0053	0.0023	0.0065
x4	0.0063	0.0006	0.0027	0.002š2	0.0024	0.0021	0.0063
. . . .							
x19	0.0289	0.0074	0.0037	0.0017	0.0016	0.0017	0.0289
x20	0.0537	0.0302	0.0035	0.0141	0.0117	0.0117	0.0000
Si	0.2785	0.1460	0.1524	0.1194	0.1472	0.1402	
Ki	0.9894	0.5188	0.5415	0.4241	0.5230	0.4981	
Rank of technologies	1	4	2	6	3	5	

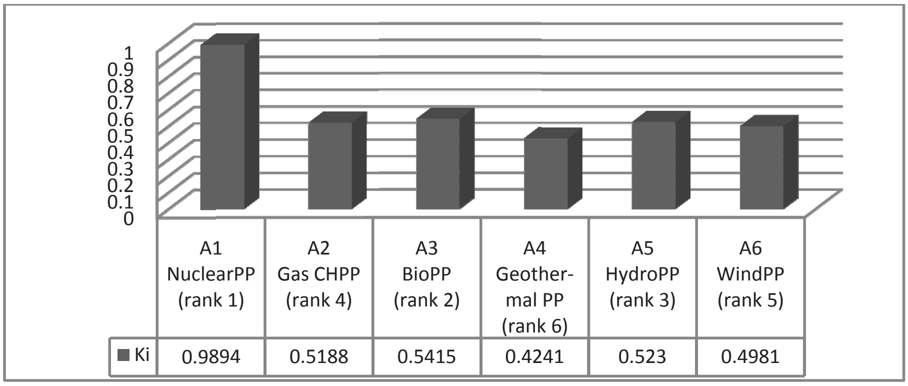

Fig. 2. Comparison of foundation installment alternatives performance level

In case of Lithuania this energy generation technology is the most reasonable type of technologies related to renewable energy sources. On the basis of results obtained in Table 3 it can be concluded that according to selected criteria reflecting the effectiveness of pile-columns construction and their weights, the most reasonable alternative according to the calculation results is first (A_1). The priority order of the investigated pile-columns installment alternatives can be represented as equation (10). A graphic form of the evaluation results is presented in Figure 2.

$$\boldsymbol{A_1 > A_3 > A_5 > A_2 > A_6 > A_4} \quad (10)$$

5. Conclusions

Selection of criteria and creation of the universal criteria system for analysis of the sector under consideration constitute the main trend of the research aimed at the analysis of the energy sector development tendencies, selection of alternative technologies or determining efficiency of separate energy generation technologies. It is vital to determine the criteria ratio characterising different aspects, to ensure correct selection of criteria significant for the particular analysis and to perform sufficiently extensive researches enabling to evaluate their weight of importance in a reliable manner. This would enable to create more universal decision support systems and develop their application. The outcome of the carried out research is the creation of the set of criteria that may be further developed and applied for the analysis of other analogous objects.

Selection and application of appropriate multiple criteria analysis methods, such as AHP and ARAS multiple criteria methods used for this research under consideration, leads to an integrated evaluation of technical, economical, environment protection and social rated aspects. The research showed that the method of AHP (Analytic Hierarchy Process) may be practically used for determining weights of importance of the qualitative criteria when the quality of alternatives is ranked by many different evaluators. The multiple criteria method ARAS enables to rate technologies by means of simple calculations and to perform their analysis. Analysis of qualitative and quantitative criteria helped rate the energy generation technologies considering their institutional, economic, technological, environmental and social aspects and rank them in order of priority. Use of two multiple criteria methods make the research result more reliable.

In summary it could be emphasized that evaluation of economic, technological, environment protection and social consequences of intervention into markets enables to take a decision regarding the efficiency, acceptability, compatibility with the society's opinion of the selected technologies and, to this matter, may lead to selection of more efficient technologies, more attractive ones for the society, including of better quality from the environment protection point of view. Application of multiple criteria methods provides support in solving problems of different ranking arising in the energy sector. Such decision making support method may be a vital component in substantiating the energy development scenarios and especially in seeking to facilitate the process of selection of different technologies.

Acknowledgements

The Lithuanian Science Board funded the performance of this research, including drafting of the material for publication, within the frame of the scientists and other researchers mobility and student scientific works stimulation instrument (VP1-3.1-ŠMM-01).

References

[1] Aras H, Erdogmus S, Koc E. Multi-criteria selection for a wind observation station location using analytic hierarchy process. *Renewable Energy*, 2004; **29**:1383-1392.

[2] Angelis-Dimakisa A, et al. Methods and tools to evaluate the availability of renewable energy sources. *Renewable and Sustainable Energy Reviews*, 2011; **15**:1182–1200.

[3] Grunwald A. Energy futures: Diversity and the need for assessment. *Futures*, 2011; **43**:820-830.

[4] Catalinaa T, Virgoneb J, Blancoc E. Multi-source energy systems analysis using a multi-criteria decision aid methodology. *Renewable Energy*, 2011; **36**:2245–2252.

[5] Streimikiene D, Ciegis R, Grundey D. Energy indicators for sustainable development in Baltic States. *Renewable and Sustainable Energy Reviews*, 2007; **11**:877-893.

[6] Vera I, Langlois L. Energy indicators for sustainable development (Third Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems). *Energy*. 2007; **32**:875-882.

[7] Schlör H, Fischer W, Hake JF. Methods of measuring sustainable development of the German energy sector. *Applied Energy*. 2013; **101**:172-181.

[8] Sliogeriene J, Kaklauskas A, Zavadskas EK, Bivainis J, Seniut M. Environment factors of energy companies and their effect on value: analysis model and applied methods. *Technological and Economic Development of Economy*. 2009; 15: 490–521.

[9] Sovacool BK, Mukherjee I. Conceptualizing and measuring energy security: A synthesized approach. *Energy*. 2011; 36: 5343-5355.

[10] Ulucan A, Atici K.B. Efficiency evaluations with context-dependent and measure-specific data envelopment approaches: An application in a World Bank supported project. *Omega*. 2010; 38: 68-83.

[11] Løken E. Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews*. 2007; 11: 584–1595.

[12] Pohekar SD, Ramachandran M. Application of multi-criteria decision making to sustainable energy planning—A review. *Renewable and Sustainable Energy Reviews*. 2004; 8: 365–381.

[13] Wang JJ, Jing YY, Zhang ChF, Zhao JH. Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews*. 2009; 13: 2263–2278.

[14] Heo E, Kim J, Boo KJ. Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP. *Renewable and Sustainable Energy Reviews*. 2010; 14: 2214-2220.

[15] Kaya T, Kahraman C. Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul. *Energy*. 2010; 35: 2517-2527.

[16] Das MCh, Sarkar B, Ray S. A framework to measure relative performance of Indian technical institutions using integrated fuzzy AHP and COPRAS methodology. *Socio-Economic Planning Sciences*. 2012; 46: 230-241.

[17] Daima TU, Li X, Kim J, Simms S. Evaluation of energy storage technologies for integration with renewable electricity: Quantifying expert opinions. *Environmental Innovation and Societal Transitions*. 2012; 3: 29– 49.

[18] Zavadskas EK, Turskis Z, Vilutiene T. Multiple criteria analysis of foundation instalment alternatives by applying Additive Ratio Assessment (ARAS) method. *Archives of Civil and Mechanical Engineering*. 2010; 10: 123-141.

[19] Beccali M, Cellura M, Mistretta M. Decision-making in energy planning: Application of the ELECTRE method at regional level for the diffusion of renewable energytechnology. *Renewable Energy*. 2003; 28: 2063–2087.

[20] Papadopoulos A,Karagiannidis A. Application of the multi-criteria analysis method ELECTRE III for the optimisation of decentralised energy systems. *Omega*. 2008; 36: 766-776.

[21] Cavallaro F. A comparative assessment of thin-film photovoltaic production processes using the ELECTRE III method. *Energy Policy*. 2010; 38: 463-474.

[22] Haurant P, Oberti P, Muselli M. Multicriteria selection aiding related to photovoltaic plants on farming fields on Corsica island: A real case study using the ELECTRE outranking framework. *Energy Policy*. 2011; 39: 676-688.

[23] Theodorou S, Florides G, Tassou S. The use of multiple criteria decision making methodologies for the promotion of RES through funding schemes in Cyprus, A review. *Energy Policy*. 2010; 38: 7783-7792.

[24] San Cristóbal JR. Multi-criteria decision-making in the selection of a renewable energy project in Spain: The VIKOR method. *Renewable Energy*. 2011; 36: 498-502.

[25] Kaya T, Kahraman C. Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Systems with Applications*. 2011; 38: 6577–6585.

[26] Wang JW,. Cheng CH, Huang KCh. Fuzzy hierarchical TOPSIS for supplier selection. *Applied Soft Computing*. 2009; 9: 377-386.

[27] Lee WSh, Lin LCh. Evaluating and ranking the energy performance of office building using technique for order preference by similarity to ideal solution. *Applied Thermal Engineering*. 2011; 31: 3521-3525.

[28] Behzadian M, Otaghsara SK, Yazdani M, Ignatius J. A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*. 2012; 39: 13051-13069.

[29] Behzadian M, Kazemzadeh RB, Albadvi A, Aghdasi M. A comprehensive literature review on methodologies and applications. *European Journal of Operational Research*. 2010; 200: 198-215.

[30] Saaty T. How to make a decision: the analytic hierarchy process. *European Journal of Operations research*. 1990; 48: 9–26.